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USE OF THE PERFORMANCE ASSESSMENT BATTERY TO DETERMINE MASK WEARABILITY

David M. Caretti

RESEARCH AND TECHNOLOGY DIRECTORATE

June 1997

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13. ABSTRACT *(Maximum 200 words)*
The objective of this investigation was to evaluate the ability of the Performance Assessment Battery (PAB) to determine mask wearability. The PAB was customized to assess the psychological domains that most influence subjective comfort including a profile of mood state and measurements of sustained attention and reaction time. This PAB battery was administered before, during, and after 60 min of treadmill walking at a moderate intensity. Subjects completed three experimental conditions of mask wear; no mask, wear of the U.S. Army M40 respirator with a standard C2 filter canister, and wear of the M40 with a C2 canister that had its airflow resistance cut in half. These test conditions were selected to enable us to evaluate the ability of the chosen PAB tasks to assess wearability of respirators with significantly different breathing resistances. Results showed that response accuracy, speed, and throughput (responses/min) were analogous between conditions, suggesting that mask acceptability, as measured by the PAB, was similar between the three mask wear conditions. Factors related to exercise intensity and differences in mask inspiratory resistances suggest that additional research may be needed before the value of the PAB as a tool for assessing mask acceptability by wearers can be determined.

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PREFACE

The work described in this report was authorized under Project No. 10161101A91A, In-House Laboratory Independent Research, Project No. 10. This work was started in May 1996 and completed in July 1996

In conducting the research described in this report, the investigators adhered to U.S. Army Regulation 70-25, Research and Development--Use of Volunteers as Subjects of Research, dated 25 January 1991, as promulgated by the Office of The Surgeon General, Department of the Army. Approval for use of the human volunteers was granted by the U.S. Army Edgewood Research, Development and Engineering Center (ERDEC) Human Use Committee, Protocol Log No. 9601S.

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USE OF THE PERFORMANCE ASSESSMENT BATTERY TO DETERMINE MASK WEARABILITY

1. INTRODUCTION

Subjective comfort or mask acceptability by the wearer may be the overriding factor that determines mask wearability. Therefore, the primary objectives in mask development should be to design a mask that not only protects the user but is comfortable to wear. However, an adequate understanding of the psychological component of mask wear has not been established. Previous research has provided some insight on the effects of respirator wear on psychological and cognitive performance in the absence of other stressors through the use of computerized assessment techniques (2,3,9), but a simple, effective means for quantifying a respirator as subjectively good or bad in terms of wearer acceptability has not been established. One reason for this is that assessment of mask wearability is difficult because it involves the psychological domains of mood state, anxiety and cognitive function. In fact, some suggest that subjective comfort or mask acceptability by the wearer may be the overriding factor that determines mask wearability (10). In any case, mask wearability has never been adequately measured.

Mask developers need a tool that can provide accurate information on the wearablilty of any mask prototype in a timely manner to register user acceptance of designs before transferring development of any specific mask to the next phase. Such a tool could effectively reduce user acceptance problems years before production and fielding. The Walter Reed Performance Assessment Battery (PAB), a research tool designed for following performance changes over time, treatments, or levels (8), was recently identified as a potential means to assess mask wearability. The PAB contains various tasks that assess subject mood state, anxiety, and cognitive function and is designed so that the duration, number and type of tasks can be customized to different experimental needs. Results are then administered and analyzed automatically. The PAB has been used for studying the effects of sustained soldier performance, heat stress and physical fatigue on cognitive function. Therefore, it was hypothesized that the PAB, customized and administered to individuals wearing respiratory protective masks, could serve as an assessment of mask acceptability. If this could be established as such, the PAB could serve to aid mask designers in the decision making process for development of any mask design. Thus, the primary objective of this investigation was to evaluate the ability of the PAB to determine mask wearability.

2. METHODS

2.1 *Subjects*

Eight subjects (7 male and 1 female) aged 30-42 years (mean age 35 years) were recruited to participate in this study. Volunteers were obtained from the civilian personnel employed at Aberdeen Proving Ground, Edgewood Area, MD. Volunteers were thoroughly briefed on the nature and purpose of the study and informed consent was obtained from each volunteer upon completion of a volunteer agreement affidavit.

2.2 *Experimental Procedures*

2.2.1 *PAB Configuration*

The PAB was customized to assess the psychological domains that most influence subjective comfort including a profile of mood state and measurements of sustained attention and reaction time. Thus, the PAB was configured to include the mood scale, serial addition/subtraction, logical reasoning, four-choice serial reaction time, and 10-choice reaction time tasks. All tasks were presented via a computer (Unisys 816 PC, VGA color monitor, and an Instacal CIO-CTR5 timer board). The mood scale task consisted of a three point scale (1-3) with the word anchors of "not at all," "somewhat or slightly," and "mostly or generally." Thirty-six adjectives that describe different mood states were presented in random order to the subject. Examples of these include "calm" and "energetic." Subjects responded by depressing the number that best described the degree to which they currently felt in relation to the presented adjective. The 36 adjectives represented the six mood factor scores of Anger, Happiness, Fear, Depression, Activity, and Fatigue. An overall mood disturbance score was obtained from the factor scores.

The serial addition/subtraction task was a mental arithmetic task requiring sustained attention. Two randomly selected digits and either a plus or minus sign were displayed sequentially in the same screen location, followed by a prompt symbol. The subject performed the indicated mathematical operation and entered the least significant digit of the result (e.g., "7, 5, +" equals 12, so enter 2). Scores were provided for the number of correct and incorrect responses (i.e., response accuracy), speed of response, and throughput (correct responses per minute).

Logical reasoning involved an exercise in transformational grammar. Sustained subject attention was an aptitude also needed for this task. The letter pair "AB" or "BA" was presented along with a statement describing the order of the letter pair (e.g., "B follows A" or "A is not preceded by B"). The subject had to decide whether the statement was the "Same" or "Different" from the presented letter pair and responded by pressing the "S" or "D" key. If no valid response occurred within 30 s, a beep was sounded, the screen went blank, and the next trial was presented. Summary data included scores for response accuracy, speed of response, and throughput.

For the four-choice serial reaction time task, a red square appeared in one of four boxes positioned in the center of the computer screen and the subject pressed a corresponding button on the numeric key pad of the key board as quickly and as accurately as possible. Again, scores were provided for accuracy, speed of responses, and throughput.

The 10-choice reaction time task was a simple reaction time task that also served as a control task for serial addition/subtraction, and as a practice doubler to hasten stability on the keypad. A single number from zero to nine was presented in the center of the screen and subjects responded by pressing the corresponding number on the numeric key pad as quickly as possible.

2.2.2 *Test Conditions*

The particular conditions of mask wear in this study were selected based on the different physiological encumbrances they imposed upon a wearer. All subjects completed three random test iterations. One test involved no mask wear and served as the control condition for each subject. Mask wear tests required wear of the U.S. Army M40 respirator (Figure 1). For one respirator trial, the M40 was configured with a standard C2 air-purifying canister mounted to the mask. The second mask wear trial required wear of the M40 with a C2 canister with half the airflow resistance of the standard C2 canister mounted to the mask. It was hypothesized that this test scenario would enable us to evaluate the ability of the chosen PAB tasks to assess wearability of respirators with significantly different breathing resistances.

Figure 1. U.S. Army M40 Respirator

In order to create a C2 air-purifying canister with half the airflow resistance of a standard C2, a canister was modified by removing its carbon filter bed. A small diameter hole was drilled into the side of a C2 canister in the area of the carbon bed and the carbon granules were drained from the canister. Pieces of insulated wire were then stuffed into the carbon bed cavity of the canister to increase the weight of the modified canister to be equal to that of a standard C2. Weight of the standard and modified C2 canisters were measured using a Sartorius Laboratory Balance (Model L2200 S). Canister airflow resistances were tested while mounted on an M40 placed on a headform airflow resistance tester (ATI Q-213 Resistance Tester, Hamilton Associates, Inc.). Resistances were measured at an airflow rate of 85 $L \cdot min^{-1}$. Canister weights and resistances are listed in Table 1.

Before data collection procedures were initiated, subjects reported to the laboratory to complete several practice trials of the PAB test battery chosen for this study. Subjects completed at least three practice trials of the customized PAB battery to become familiar with the various tasks, the position of the computer key board, and with use of the numeric key pad

Table 1. C2 Canister Characteristics

Canister	Weight (g)	Resistance (mm H_2O)
Standard	282.1	46.0
Modified	281.9	22.3

of the key board. A test administrator went through the instructions with each subject to provide further explanation if necessary. The results for these dry-runs were discarded. Since subjects would be required to complete the PAB while walking on a treadmill, at least one practice trial was conducted during treadmill walking. Volunteers were given the option to complete additional practice trials if they felt it would increase their familiarity with the PAB tasks.

Subjects were prepped for heart rate monitoring upon arrival to the laboratory for testing. Heart rate was monitored continuously during and following exercise by recording a bipolar 3-lead ECG (Quinton Q3000 ECG monitor). Heart rate was recorded at 10 minute intervals during exercise. If a subject was scheduled to complete a mask wear iteration, M40 mask fitting was completed following heart rate monitoring preparations.

Before testing commenced, subjects completed the State-Trait Anxiety Inventories (7). The trait anxiety inventory evaluated how respondents felt "in general." This questionnaire was administered to each subject only at the beginning of their initial test iteration. The state anxiety inventory assessed how subjects felt at a particular moment. These questionnaires have been used extensively in mask wear research and served as benchmarks of subject anxiety tendencies. Subjects then completed one practice session of the PAB to reacquaint themselves with what was to be displayed on the computer screen, which keys would be used, and what the rules were for each task. Once subjects completed the practice trial, testing commenced with subjects performing the tasks of a pre-exercise PAB battery.

A simulated road march involving continuous walking for 60 minutes at a work load of 50% of predicted maximum heart rate (220 minus age) was then completed by each subject. Speed and grade of the treadmill (Quinton Q65) were adjusted as needed to elicit and maintain the target work intensity. Subjects repeated the tasks of the PAB after 20 and 40 minutes of exercise. Subjects continued to walk while completing these PAB iterations.

Subjects provided subjective self-ratings of mask comfort after initial donning, every 10 min of exercise, and immediately post-exercise through the use of the Breathing Apparatus Comfort Scale (BAC). The BAC is an 11-point scale with word descriptive anchors where 10 = most comfortable and 0 = most uncomfortable.

Following the treadmill walk, subjects completed a final iteration of the PAB. Subjects remained masked while completing the final PAB trial during mask wear trials. The state anxiety questionnaire was repeated following exercise after subjects removed their mask.

3. RESULTS

Performance results for the PAB serial addition/subtraction, logical reasoning, and four-choice serial reaction time task are presented in Tables 2 through 4. Data are presented for the different experimental conditions over time. Calculated mask performance ratings represent the ratios of performance measures during mask wear for each of the different C2 canister configurations compared to the no mask condition.

A two-way analysis of variance showed that average response accuracy scores, measured as the percentage of correct subject responses, were analogous between the three experimental conditions within each task and for each measurement period (Table 2). In addition, no significant differences were found between time periods within each condition. Performance ratings were also similar for the different inspiratory resistance test conditions. In general, performance rating scores showed that response accuracy for the three tasks was not influenced by mask wear.

Table 2. Response Accuracy (% correct) of PAB Tasks.

Task	**Time**	**No Mask**	**C2 Stnd**	**PR Stnd**	**C2 Mod**	**PR Mod**
	Pre	95.8±3.6	96.3±2.3	100	94.0±4.0	98
Serial +/-	20 min	94.8±6.0	94.5±6.6	100	97.0±1.5	102
	40 min	97.8±2.5	95.7±5.0	98	95.8±3.5	98
	Post	96.3±2.9	95.0±8.9	99	93.8±5.4	97
Logical	Pre	88.3±15.5	87.5±13.9	100	83.9±14.7	96
Reasoning	20 min	89.4±11.9	88.6±17.8	98	86.3±14.2	97
	40 min	90.6±13.8	90.2±15.3	99	90.6±12.0	103
	Post	89.1±16.1	87.9±17.3	98	90.8±8.4	105
	Pre	99.8±0.7	99.8±0.7	100	99.5±0.9	100
4-Choice RT	20 min	98.3±2.3	99.5±0.9	99	97.3±3.7	101
	40 min	99.3±1.0	99.3±1.5	99	98.5±2.8	100
	Post	99.8±0.7	99.8±0.7	100	99.8±0.7	100

Definition of Terms: Serial +/- = serial addition/subtraction; 4-Choice RT = four choice reaction time; Stnd = standard C2 resistance; Mod = modified C2 resistance; and PR = performance rating.

Separate two-way analyses of variance performed on the speed and throughput data resulted in findings similar to accuracy results. No statistical differences were found between experimental conditions within each task and time of measurement did not alter responses within each condition (Table 3). Speed and throughput performance ratings for the modified C2 resistance condition for the serial addition/subtraction task were less than standard C2 ratings at all times, but no significant differences were found. Speed and throughput performance decrements during mask wear ranged from zero to 15% and varied over time.

Independent of time of measurement, a significant ($F=3.4$, $df=2,94$, $p=0.03$) main effect of mask wear condition was found for speed of response for the serial addition/subtraction task. Post-hoc analysis using Duncan's multiple range test showed that average response speed was significantly less for the modified C2 test condition compared to the other conditions (Table 5).

Table 3. Speed (responses/min) of Response for PAB Tasks.

Task	Time	No Mask	C2 Stnd	PR Stnd	C2 Mod	PR Mod
Serial +/-	Pre	64.5±9.3	63.8±13.3	100	58.9±10.0	93
	20 min	67.6±10.7	70.8±11.4	106	60.4±14.4	89
	40 min	70.6±10.0	76.3±14.5	112	69.6±16.3	101
	Post	70.0±9.3	70.3±11.1	102	61.0±12.8	88
Logical Reasoning	Pre	18.2±5.1	17.2±4.6	96	16.8±6.2	92
	20 min	18.0±5.1	18.7±5.1	105	18.3±4.7	105
	40 min	20.2±5.2	19.0±4.1	97	17.2±5.7	86
	Post	20.4±4.6	18.3±5.0	91	16.8±5.2	82
4-Choice RT	Pre	139.5±19.2	140.6±15.2	102	145.0±18.7	105
	20 min	145.8±17.4	147.9±15.6	102	139.8±23.4	96
	40 min	153.0±19.7	150.2±21.6	99	146.4±21.3	96
	Post	149.4±15.8	155.1±17.0	103	144.8±22.1	97

See Table 2 for definition of terms.

Table 4. Throughput (hits/min) for PAB Tasks.

Task	Time	No Mask	C2 Stnd	PR Stnd	C2 Mod	PR Mod
Serial +/-	Pre	61.7±9.0	61.4±13.1	100	55.5±10.5	91
	20 min	63.9±10.6	67.1±13.2	106	58.6±13.8	91
	40 min	69.2±10.9	73.3±16.0	110	70.0±17.4	99
	Post	67.1±10.0	66.6±11.9	100	57.5±14.0	86
Logical Reasoning	Pre	16.3±6.2	15.4±5.8	96	14.8±7.6	90
	20 min	16.1±5.3	16.7±6.2	103	16.0±5.4	103
	40 min	18.4±6.0	17.3±5.3	97	16.0±6.5	89
	Post	17.9±4.6	16.3±6.4	88	15.5±5.6	85
4-Choice RT	Pre	139.1±18.8	140.2±14.7	102	144.3±18.8	105
	20 min	143.2±16.8	147.1±15.4	103	136.1±24.4	96
	40 min	151.8±19.5	149.1±22.2	99	144.0±20.1	95
	Post	149.1±16.1	154.7±16.8	103	144.4±21.7	97

See Table 2 for definition of terms.

A separate one-way analysis of variance for the throughput variable showed a significant main effect of mask condition with a p-value equal to 0.05. Subsequent analysis with the Duncan's multiple range test again indicated that average subject throughput was lower during the modified C2 mask wear trials (Table 5). No other main effects of mask experimental condition were observed.

Table 5. Serial Addition/Subtraction Data Independent of Time of Measurement.

Measure	**No Mask** (n=32)	**C2 Stnd** (n=31)	**C2 Mod** (n=32)
Speed (responses/min)	68.2±9.7	70.1±12.7	62.5±13.6[1]
Throughput (hits/min)	65.5±10.1	66.9±13.5	59.6±14.2[1]

1= significantly different vs. No Mask and C2 Stnd

Analysis of mood scale responses was performed using multivariate analysis of variance with unique sums of squares for the variables of condition and time of measurement. Results of this analysis found no significant interactive effects of condition and time on the six mood factor scores of Anger, Happiness, Fear, Depression, Activity, and Fatigue. In addition, no significant main effects of time or condition were observed.

No differences in state anxiety were observed before and after exercise within test conditions. Likewise, similar state anxiety scores were found between mask wear conditions. Self-reported BAC scores did not differ between the masked conditions.

4. DISCUSSION

The results of this study showed that respirator wear over time had little effect on performance of cognitive tasks during moderate intensity physical work. Previous research suggests that such a finding should not be unexpected. Caretti *et al.* (2) found that reaction time and decision making speed were not significantly altered during 10 hours of continuous respirator wear under non-exercising conditions. Likewise, others have reported that respirator wear did not influence cognitive performance during completion of a variety of physical and psychomotor tasks over time (4,10). In contrast, Kamimori *et al.* (6) found that low intensity exercise negatively influenced cognitive performance. Similarities in test methods between the current study and the investigation by Kamimori *et al.* suggest that mask wear in general may act to negate any negative influences that low intensity exercise may have on cognitive performance. However, we found no significant effects of exercise on task performance during the unmasked trials of our study. Therefore, results of this investigation contradict the findings of Kamimori *et al.*.

The finding of a significantly slower response speed and lower response throughput for the serial addition/subtraction task independent of exercise for the low resistance mask condition compared to the standard resistance and control conditions was not expected. This finding suggests that decreasing mask inspiratory resistance detrimentally influences some cognitive performance. Previous studies have reported no change or improved cognitive functioning during wear of the M40 respirator with a standard C2 filter canister, a result that has been attributed to a filtering effect of the mask that serves to help masked subjects to better focus on completion of the tasks compared to unmasked subjects (2,3). However, filtering of peripheral distractions would seem to be equivalent for the two resistance conditions in this study because the hardware items of the mask were identical for each condition. A possible explanation for the observed decrease in performance of the serial addition/subtraction task for the low resistance mask compared to the standard resistance condition is that the reduced respiratory burden served to lower the overall stress of wearing the mask. This, in-turn, may have acted to decrease subject arousal. Increased arousal caused by the stress of wear of the standard M40 configuration has been suggested to improve subject concentration and stimulate performance (3). Therefore, the level of arousal of subjects wearing the low resistance mask may have been too low to stimulate performance on the serial addition/subtraction task. In any case, the overall effect of mask wear with a lower inspiratory resistance on cognitive performance is probably minimal since only one of the three cognitive tasks was influenced by this condition.

The PAB tasks that were selected for this study were chosen to assess main cognitive domains, namely sustained attention and logical reasoning abilities. In addition, subject mood was measured to quantify mood states for the three conditions of mask wear. All of these factors were selected to provide feedback as to mask acceptability of the subjects during the chosen exercise scenario. Since the results of the study do not suggest that mask acceptability was different between the three conditions, it might be argued that the chosen PAB battery failed as a tool to measure mask wearability. However, failure to see differences in cognitive performance and mood between no mask wear, wear of the M40 with a standard C2, and wear of the M40 with a modified canister may be the result of factors other than the ability of the PAB to assess mask acceptability. Certainly, before testing commenced, it was anticipated that subjects would be more comfortable during low resistance trials which would result in a better overall mood state during testing. Mood, state anxiety, and BAC scores, however, were identical between conditions, indicating that subjects were unable to detect a difference in the resistance levels of the two masked trials. In fact, one subject was adamant in his perception that the low resistance mask was the standard condition and vice versa. This inability to notice a difference in breathing resistances most likely limited the chances of seeing significant differences in mood scores and cognitive performance. Larger differences in breathing resistances for the masked conditions may have resulted in significant differences in cognitive performance and mood between conditions.

Another factor to consider is that of the exercise intensity chosen for testing differences in breathing resistance. It has been suggested that in order to assess the effects of mask breathing resistance on performance, testing must be done at an intensity that causes the respiratory system to be the limiting factor in exercise performance (5). Current data suggests that this intensity falls between 85-90% of maximal oxygen consumption, or 75-85% maximal heart rate (1). Since exercise intensity averaged 52% of predicted subject maximal heart rates, stress on the respiratory system was not significant. Results from the PAB test scores could be different between test conditions if testing was conducted to impose a greater stress on the respiratory system, but completion of the computerized tasks would be more difficult during continuous exercise and would likely result in more errors in keyboard use due to greater arm, hand, and head movement due to increased treadmill speeds and grades. However, discontinuous high intensity exercise can not be ruled out as a means to assess the effects of breathing resistance on PAB scores.

5. CONCLUSIONS

The results of the study suggest that mask acceptability, as measured by the PAB, was similar between the three mask wear conditions. However, an inability to find differences in cognitive performance and mood between test conditions does not in and of itself mean that the chosen PAB battery failed as a tool to measure mask wearability. The combination of a low exercise intensity and an undetectable difference in mask inspiratory resistances may have limited the ability of the PAB to determine mask wearability. Additional research is warranted before the value of the PAB as a tool for assessing mask acceptability by wearers can be determined.

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